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# IMPACT INITIATION SENSITIVITY OF REACTIVE MATERIALS A SELECTIVE BIBLIOGRAPHY INCLUDING ABSTRACTS

PREPARED BY

RESEARCH AND DEVELOPMENT DEPARTMENT

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U.S. Naval Ammunition Depot
Crane, Indiana

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# IMPACT INITIATION SENSITIVITY OF REACTIVE MATERIALS-- A SELECTIVE BIBLIOGRAPHY INCLUDING ABSTRACTS

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# IMPACT INITIATION SENSITIVITY OF REACTIVE MATERIALS--
# A SELECTIVE BIBLIOGRAPHY INCLUDING ABSTRACTS

## PART I

## PURPOSE

The purpose of this report is to provide those concerned with the research, development, design, and production of explosives, pyrotechnics, and propellants, an abstracted listing of reports and articles dealing with the general subject of impact initiation sensitivities for those materials.

## SCOPE

Included in the term impact are: (1) low velocity impact characteristic of the type generated in the various impact tests where a weight is allowed to free-fall under the influence of gravity and impact a reactive material resting upon a fixed rigid plate; (2) bullet impact characterized by firing either military ammunition of selected small calibers or specially designed projectiles of small caliber into a reactive material; and (3) ultra-high velocity impact of reactive material by explosively driven fragments or projectiles.

This listing is by no means an exhaustive one. It is to be regarded as the first in a series which will be complete to date.

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13 ABSTRACT

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F. D. Altman, *The Impact Sensitivity of Confined High Explosives as a Function of Their Elevated Temperature*, Report No. 1573, U. S. Naval Proving Ground (25 Nov 1957).


## ABSTRACT

A series of tests were made in which explosive filled cylinders were heated to 70°C and 95°C and then dropped a distance of 20 feet onto a studded steel plate. Half of the cylinders were filled with Compostion B and half with HBX-1. The walls of the cylinders were of two thicknesses, one to permit penetration by the studs, the other to prevent such penetration. The high explosive did not burn or react explosively as a result of drops of the cylinders. It was concluded from this that no unacceptable increase in initiation sensitivity will occur as a result of these cased explosives being at temperature levels up to 95°C when subjected to drop impacts and severe case deformations. Possible increases in sensitivity as a result of elevated temperatures, under conditions different from those of this test, are discussed briefly.

**I. N. Burlingame**, *Impact Sensitivity Tests on Ball Powder, Nitrocellulose, and Nitroglycerine*, **Technical Report No. 117, Liberty Powder Defense Corporation, Badger Ordnance Works, Baraboo, Wisconsin (30 Sep 1955).**

## ABSTRACT

This report covers impact sensitivity tests as performed on Ball Powder Grains produced in the Ball Powder Auxiliary Line at Badger Ordnance Works. The program also included like tests on plant produced Nitrocellulose at varied moisture content, as well as, Nitroglycerine solutions in Ethyl Acetate at various percentages of concentration.

The types of powder tested and the cuts thereof are as follows:

| | | |
|---|---|---|
| Base Grain: | .009"/or less, "fines"<br>.025"/.016"<br>.034"/.025" | |
| Coated Grain: | .025"/.016" | 1/From Centrifuge<br>2/From Dryer |
| Glazed Grain: | .025"/.016" | |

Blended nitropulp of the type used in Ball Powder (10,000 Series) was tested at three moisture levels: 31%, 20%, and 10%, and at two thicknesses, (thin layer and 1/8" layer). Due to the lumpy nature of the material the "thin-layer" was not very uniform, but was rather consistently somewhat less than 1/16".

Nitroglycerine-ethyl acetate solutions tested were in concentrations of: 65%, 70%, 80%, and 90% nitroglycerine, by weight.

All of the cited cuts of Ball Powder base grain were tested at four different levels of moisture content. The cut of coated powder was tested at two moisture levels, from the points of production as indicated. The glazed cut was also tested at two levels of moisture content.

The purpose of these tests and the recorded results thereof, was to determine the degree of sensitivity of the cited products in various stages of production and thereby accumulate a more complete dossier thereon, as well as obtaining information toward determining their correlative relationship with required measures of safety necessary in their manufacture and handling.

J. J. Caven, *Sensitivity Drop Tests on Loose Pyrotechnic Powder Compositions of Incendiary, Igniter and Tracer Types*, Memorandum Report MR-564, Pitman-Dunn Laboratories, Frankfort Arsenal, Philadelphia, Pennsylvania (Oct 1953).


## SUMMARY

A simplified procedure for determining the sensitivity of loose pyrotechnic powders is described in this Tracer Information Bulletin. It provides a method for obtaining reliable sensitivity drop test results with expendable drop test pin inserts. Essentially, the method consists in dropping a steel ball a pre-determined distance against the flat steel surface of the drop pin body with subsequent impingement of drop pin insert against the composition covered area of the steel anvil.

C. A. Coakley, *Drop Sensitivity Tests of Terrier Warheads Mk 5 Mod 3 Loaded with H-6 Explosive*, Report No. 1437, Naval Proving Ground, Dahlgren, Virginia (23 Jun 1956).


## ABSTRACT

Three Terrier Guided Missile Warheads Mk 5 Mod 3 loaded with H-6 explosive were tested to determine the sensitivity of the explosive to impact.

Each of the three warheads was dropped twice, once on flat plate and once on rails, from a height of 40 feet.

All three warheads suffered case distortion but no deflagration resulted. As a result of these drops, the Terrier Guided Missile Warhead Mk 5 Mod 3 loaded with H-6 explosive appears to be sufficiently insensitive to drop impact to be satisfactory for service use.

Committee on Fillings for Aerial Bombs of Divisions 2 and 8, NDRC, *Report on HBX and Tritonal*, Report No. 5406, Office of Scientific Research and Development (31 Jul 1945) or National Defense Research Committee, Report A-337 (31 Jul 1945).

ABSTRACT

A critical compilation of the existing data on the properties of HBX, Tritonal, Torpex 2, Minol 2, RDX-Composition B, and TNT has been made, including air-blast and underwater shock-wave effectiveness, underground performance, fragmentation, contact effectiveness, detonation velocity, and so forth, as well as a discussion of sensitivity experiments, stability, and manufacturing problems. The Committee also reached certain conclusions regarding the use of these explosives in aerial bombs.

F. David, C. Fauquignon, H. Bernier, J. Potau, *Oblique Impact of a Layer of Explosive By a Metal Plate*, pg 381-5.
Fourth Symposium (International) on Detonation
U. S. Naval Ordnance Laboratory, White Oak, Maryland, 12-15 Oct 1965.

## ABSTRACT

It is known that the impact of a metal plate upon an explosive can initiate its detonation. When the metal plate comes in contact with the layer of explosive, not all at once but gradually, an oblique detonation wave is initiated. The possible configurations of flow are studied in the neighborhood of the point of impact in two-dimensional plane permanent geometry. Under certain conditions it is shown theoretically, that the compatability at the interface can be achieved only by taking into account an overdetonation wave of given characteristics. Experiments point to the existence of such a wave. By tracing graphs its characteristics may be measured.

S. Duck and L. Hampton, *Sensitivity of Explosives III, Sensitivity of Explosives to Impact, Period 1 July 1956 - 1 November 1956*, NAVORD Report 4458, Naval Ordnance Systems Command, Washington, D. C. (1 Nov 1956).


## ABSTRACT

Impact sensitivity data of explosive compounds and compositions tested by the Explosives Properties Division of the Explosives Research Department during the period 1 July 1956 to 1 November 1956 are included in this report. The data reported include tests of the sensitivities of certain common primary explosives when wet, some preliminary data on explosives tested in the form of cast or pressed pellets, and the results of miscellaneous tests requested by various groups. These include an extended series of tests of TNT under various conditions, the results of which indicate the considerable variability in the sensitivity measurements of such samples. The type of machine and tools employed, the method of treating the data, and the preparation of the samples are described.

S. Duck, G. Reynolds, and L. Starr, *Sensitivity of Explosives to Impact, Period 1 May 1955 to 1 November 1955*, NAVORD Report 4212, Naval Ordnance Systems Command, Washington, D. C. (13 Mar 1956).


## ABSTRACT

Impact sensitivity data of all explosive compounds. and compositions tested by the Explosives Properties Division of the Explosives Research Department during the period 1 May 1955 to 1 November 1955 are included in this report. Impact sensitivities of approximately thirty samples of dinitropropyl trinitrobutyrate (DNPTB) which were requested by the Chemistry Division have been omitted from this report. It is expected that these data will be included in a report on dinitropropyl trinitrobutyrate at a future date. Impact sensitivities of trinitroethyl trinitrobutyrate (TNETB) samples were reported in NAVORD Report 3853 and NAVORD Report 3955.

The impact sensitivities of TNETB compositions investigated during this period are reported herein.

The results in this report have been divided into two parts. One part includes results of testing explosives prepared by various contractors, in connection with the Navy's new high explosive program. The other part includes all special tests made for divisions of the Department, and the Bureau of Ordnance.

The type of machine and tools employed, the basic test procedure, method of treating data and the preparation of samples are described.

J. Gallagher, R. E. Cupp, W. Smith, *Feasibility of Detection Systems Employing Microwave Emissions from Hypervelocity Impact*, Technical Report No. AFATL-TR-69-6, (Jan 1969).


## ABSTRACT

A millimeter wave receiver was designed and constructed for operation in the 90 $GH_z$ and 70 $GH_z$ frequency regions. Two field tests were conducted at the Eglin Air Force Base hypervelocity impact gun for observations with the receiver. In the second field trip, pulses were observed with the receiver tuned to receive 68.4 $GH_z$. The pulse is tentatively assigned to originate from an emissive transition in aluminum. The receiver was employed as a radiometer and detected emission from a flame seeded with lithium fluoride. The observation performed at 89,740 $MH_z$ indicates that the emission is associated with the $J = 0 \rightarrow 1$ rotational transition of $Li^6 F^{19}$. A small effort on molecular beam spectroscopy of high temperature materials is described.

W. A. Gey, E. D. Besser, and P. G. Rivette, *Impact Sensitivities*, Report No. 5335, Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland (18 Oct 1956).


## ABSTRACT

Impact sensitivity data collected by the Chemistry Division, Research Department, Naval Ordnance Test Station, during the past several years are compiled in this report. These data have been gathered from a number of projects: desensitization studies of nitroglycerin and RDX, cobalt complexes, and primer and explosive mixtures. A Bureau of Mines impact machine with Type 12 tools has been used for the tests.

Impact sensitivity data on well known explosive materials are compared with the results obtained by the Naval Ordnance Laboratory and the Armour Research Foundation. The relative sensitivities are generally of the same order.

A general table of pure compounds is presented in the order of their decreasing sensitivity. Other tables list the impact sensitivities of RDX desensitized by coatings of fluorocarbons and explosive waxes; results of studies on explosive cobalt complexes, explosive mixtures based on RDX, and primer materials are included.

N. Griffiths, R. McN. Laidler, *The Explosive Initiation of Trinitrophenylmethylnitramine By Projectile Impact,* J. Chem. Soc. pg. 2304-9, (1962).


## ABSTRACT

The initiation of trinitrophenylmethylnitramine by projectile impact has been studied by high-speed photography and it is shown that the initiation originates from the shock wave which enters the explosive on impact. The shock wave releases energy and the resulting balance of energy gained and lost by the shock wave determines the probability of detonation.

N. Griffiths, R. McN. Laidler, S. T. Spooner, *Some Aspects of The Shock Initiation of Condensed Explosives*, Combustion and Flame, Vol. 7, pg. 347-52, (1963).


## ABSTRACT

The probability of the shock initiation of a number of explosives under various conditions to projectile impact has been assessed. An outline is given of the current theory of shock initiation and the experimental results obtained are discussed in the light of this theory. It is shown that the presence of an inert material reduces the shock sensitivity of an explosive by acting as a diluent, thereby reducing the number of sites at which reaction can begin.

J. R. Holden, *Noise Intensity Measurements in The Study of Impact Sensitivity*, Report No. 6740, U. S. Naval Ordnance Laboratory, White Oak, Silver Springs, Maryland, (2 Nov 1959).


## ABSTRACT

Quantitative measurements have been made of the noise intensitites produced by impact explosions of RDX, TNT, Composition A and Composition 3 under the conditions of the standard NOL impact test. The measurements show that shots with RDX can be uniquely classified as "fires" or "failures", but such classifications of shots with TNT, Composition A or Composition B must be based on an arbitrarily set critical amplitude.

It has been shown that the noise intensity from individual impact explosions of TNT varies with directions thus introducing unwanted scatter to the results of an impact sensitivity test.

J. R. Holden, *Preliminary Evaluation of Small Cast Samples for Impact Sensitivity Testing*, Report No. 4399, Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland (23 Oct 1956).


## ABSTRACT

Small cast pellets of explosive of about 35 mg. each have been prepared and tested in the NOL impact machine.

Reproducible values of the sensitivity of dinitropropyl trinitrobutyrate (DNPTB) have been obtained by means of a pellet sample technique whereas the conventional powder method gave wide variations. Preliminary sensitivity tests have been made using pellet samples on some single and multi-component explosives. The order of relative sensitivity of explosives using cast pellets and powdered sample was found to be nearly the same. Dinitropropyl fumarate (DNPF) was a notable exception to this.

M. J. Kamlet, *A Correlation of Impact Sensitivities of Explosives with Oxidant Balances*, Report No. 6126, Naval Ordnance Systems Command, Washington, D. C. (26 Sep 1958).


## ABSTRACT

A plot of logarithmic impact heights as a function of OB/100 of 84 high explosive compounds chosen at random shows points clustering about separate trends for compounds containing the N-nitro linkage and for other polynitroaliphatic compounds. The distribution about these trends indicates that there may be a linear relationship between the two parameters.

OB/100 is defined as the number of equivalents of oxidant per hundred grams of explosive above the amount necessary to burn all carbon to carbon monoxide and all hydrogen to water. In calculating this quantity an atom of oxygen represents two equivalents of oxidant, an atom of fluorine one equivalent; an atom of carbon represents two equivalents of reductant and an atom of hydrogen one equivalent.

It is demonstrated that no simple relationship between impact sensitivity and heat of detonation should be expected. A mechanism is presented to explain the observed effect of OB/100 on impact heights.

The impact sensitivity of explosive plus wax appears to be that predicted at an equivalent value of OB/100 by the trend for the class into which the explosive falls. As a consequence it is concluded that with ideal mixing "desensitization" is merely a process of dilution.

The consequence of these observations are discussed and some recommendations are made on the course of future research in high explosives chemistry.

This report describes a hitherto explicitly unnoticed relationship between impact sensitivities of explosives or explosive mixtures and their oxidant balances. The consequences of this relationship are explored. If the relationship noted herein is valid, as this limited study indicates, a new direction for improved performance explosive research is indicated which may result in greater safety. The work described in this report was performed under Task No. 800-667/76004/01.

E. L. Kendrew, J. Wenograd, *A Photographic Study of The Impact Test*, Report No. 6/R/60, Ministry of Aviation, Explosives Research and Development Establishment, (22 Mar 1960).


## SUMMARY

A synchronisition technique has been developed by means of which an impactlike explosion can be initiated and photographed with a Beckman and Whitely high-speed framing camera.

High explosives are found to react under slightly varying conditions by three distinct modes. The most frequently encountered mode is a fast burning reaction proceeding from a centre of initiation. The velocity of this propagation is 460 m/s for PETN, about 300 m/s for RDX ard 220 m/s for PETN incorporated with 10 or 20 per cent of TNT, PLTN has also been observed to react by an irregular slow burning reaction characterised by velocities near 100 m/s. The third mode of reaction is a low order detonation which proceeds at rates near 1300 m/s in PETN samples. The primary explosives lead azide and mercury fulminate detonate under the conditions employed in this investigation.

A. Le Roux, *DÉTONATION DES EXPLOSIFS, PAR LE CHOC DE CORPS SOLIDES LANCÉS A GRANDE VITESSE, (Detonation of Explosives Through the Shock of a Solid Body Launched at High Velocity)*. Me. Poudres, Vol 33, pg 283-321 (1951).

## RÉSUMÉ

Le présent mémoire expose les résultats obtenus au cours d'essais de sensibilité au choc de la balle effectués sur des explosifs suivant la méthode codifée du Laboratoire de la C. S. E.; il comport un classement des explosifs ainsi examinés, d'après leur sensibilité au choc de la balle, sous leur densité de tassement et sous leur forme habituelle d'emploi, dans les conditions expérimentales adoptées.

D. Levine, C. Boyars, *Measurement of Impact Sensitivity of Liquid Explosives and Monopropellants*, Report No. NOLTR 65-54, U. S. Naval Ordnance Laboratory, White Oak, Silver Springs, Maryland, (20 May 1965).


## ABSTRACT

Instrumentation of a standard drop-weight tester to give pressure-time records and further modification to permit high speed photography have allowed intimate study of the impact-initiation-explosion process in nitroglycerin. A plot of peak impact pressure versus concentration of conventional desensitizer (in nitroglycerin) gives a continuous, nearly linear relationship. The ratio of peak impact pressure to initial pressure is a most significant factor in determining probability of explosions of nitroglycerin. This is consistent with quasi-adiabatic compression of air bubbles as a step in the mechanism of initiation. The photographic studies support this mechanism, showing compression, breakdown of bubble structure (thereby causing more efficient heat transfer to the surrounding liquid), an induction period, and ignition starting in hot spots at the site of the bubble.

Desensitization of nitroglycerin without excessive decrease in energy and without adversely arfecting its physical properties would permit the safer processing of high specific impulse propellants. Modification of a standard sensitivity test apparatus has allowed intimate study of the impact-initiation-explosion process in nitroglycerin, which may provide clues for its more efficient desensitization.

C. Lipscomb, J. Angetti, *Factors Affecting Bullet Impact Initiation of Pyrotechnic Compositions*, RDTR 173, Research and Development Department, Naval Ammunition Depot, Crane, Indiana, (1 Sept 1970).


## ABSTRACT

Three possible modes of initiation by bullet impact of a typical magnesium, sodium, nitrate, binder illuminating system are considered. Of the three-mechanical activation, adiabatic compression, and friction--friction appears to be the dominant factor in initiation of this composition by bullet impact. A demonstrated "cure" is also cited.

E. L. Litchfield, and H. E. Perlee, *Fire and Explosion Hazards of Flight Vehicle Combustibles*, Technical Report AFAPL-TR-65-28
Bureau of Mines, U. S. Department of the Interior
Air Force Aero Propulsion Laboratory, Research and Technical Division, Air Force Systems Command,
Wright-Patterson Air Force Base, Ohio (March 1965).

## ABSTRACT

Severe explosion hazards could result from a massive spill of non-hypergolic fuel and oxidizer of a missile propulsion system; this problem would be especially severe with the high-energy systems where one or both of the propellant components are cryogens. The sensitivity of two such systems, liquid hydrogen + solid oxygen + diluent and liquid oxygen + solid hydrocarbon + diluent, has been investigated employing a projectile impact to determine the shock required to detonate these mixtures. With no diluent, each explosive system is initiated by a shock stimulus of 1.0 to 2.5 kbar. The explosive yields are such that 1-lb cryogenic mixture is equivalent to 0.6 to 2.0 lb TNT. Sodium chloride, nitrogen, and methyl cnloride had inert desensitizing effects upon the liquid hydrogen mixtures but did not reduce the explosive yield. Sodium chloride and nitrogen desensitized the liquid oxygen system; sodium chloride

or water reduced the explosive yield of this system.

Large volumes of detonable, gaseous hydrogen-oxygen mixtures would result from a massive spill of liquid hydrogen-liquid oxygen. Inhibition of detonation initiation by dry powder particle additives was investigated. The powder additives produced insignificant inhibition in comparison to that produced by gaseous diluents.

Flammability limit determinations of four additional halogenated hydrocarbons are included in a discussion of the characteristics of 10 such compounds. Most of the compounds were flammable in oxygen atmospheres at temperatures below 200°F; their combustion products included toxic halogens or helogen halides.

W. R. Lucas and W. A. Riehl, *An Instrument for the Determination of Impact Sensitivity of Materials in Contact with Liquid Oxygen*, Report DSN-TR-2-58, Army Ballistic Missile Agency (15 Oct 1958).


## ABSTRACT

An apparatus developed by the Army Ballistic Missile Agency for use in determining the impact sensitivity of materials in contact with liquid oxygen is described. The ABMA impact tester provides flexibility of testing conditions and reproducible results. Test results illustrating variables which must be controlled in impact testing are also presented.

N. Lundborg, *Comparison Between Shooting and Barrier Tests*, Fourth Symposium (International) on Detonation, pg 432-3 U. S. Naval Ordnance Laboratory, White Oak, Maryland, (12-15 Oct 1965).

## ABSTRACT

The end velocity of an Al-barrier has been measured as a function of the length. The critical end velocity has been determined for three different explosives and compared with the critical velocity in the shooting test. The result shows that the barrier test demands a somewhat higher velocity than the shooting test for the same explosive.

H. D. Mallory (Editor), *The Development of Impact Sensitivity Tests at the Explosives Research Laboratory, Bruceton, Pennsylvania During the Years 1941-1945*, Report No. 4236, Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland (16 Mar 1956).


## ABSTRACT

This NAVORD Report consists of reproductions of reports which are no longer generally available. They report work carried out in 1942-45 at the Explosives Research Laboratory, Bruceton, Pa. The Bruceton Impact Machine (now used at the Naval Ordnance Laboratory) is described, and the development work with it is fully reported. It is as a result of this investigation of 14 different tool types (hammer and anvil combinations) and of other variables affecting the test value that the present NOL standardized impact sensitivity test for high explosives was selected.

Most of the ERL work was carried out by Rogers F. Davis whose progress reports are the major portion of this NAVORD Report. Summary reports of his work have appeared in OSRD reports 804 (1942) and 5744 (1945). The first of these is also reproduced in this report.

. P. McDougall, E. H. Eyster, W. H. Rogers, *Studies of the Sensitivity of Explosives to Bullet Impact*, Report No. 3149, Office of Scientific Research and Development, (15 Dec 1943).


## ABSTRACT

The non-linear dielectric material employed in a number of small-size ceramic capacitors was investigated, particularly with regard to its usefulness at high frequencies. While the ceramic capacitors introduced previous to 1940 used linear titania materials, such as titanium dioxide, the majority of high capacitance small-size ceramic coupling capacitors now use the non-linear titanates, such as mixtures of barium and strontium titanates. The position of the Curie point suggests that the composition of these capacitors is approximately seventy-two per cent barium titanate, and twenty-eight per cent strontium titanate. A typical coupling capacitor of 0.01-microfarad capacitance has an initial dielectric constant of 6000. When a d-c voltage of 450 volts is applied, the capacitance drops to one-third of the value with no d-c voltage applied. Standard ceramic capacitors, as supplied for circuit components, are therefore suitable for all the applications to which non-linear dielectrics may be put. These applications include control of oscillator frequency by a voltage, control of phase

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H. S. Napadensky, *Initiation of Explosives by Low Velocity Impact*, pg 473-6,
Fourth Symposium (International) on Detonation,
U. S. Naval Ordnacne Laboratory, White Oak, Maryland,
(12-15 Oct 1965).


## ABSTRACT

A sensitivity test has been devised wherein cylindrical, unconfined specimens of high explosive of the order of several pounds in weight are squeezed between an explosively driven plate and a massive anvil. At one extreme of the initiation spectrum the shock transmitted is of sufficient intensity to initiate detonation before or at the instant when the shock wave reaches the face of the anvil. At the threshold of initiation however, the time between initial movement of the plate and evidence of explosion is long enough for extensive crushing of the HE to occur. The impact velocity required for initiation has been found to be strongly dependent upon the size of the explosive specimen. Sensitivity increases rapidly as the length of the specimen is decreased. Marginal initiation is the result of a slow crushing process for short samples. As specimen length is increased, the critical impact velocity approaches a limiting upper value which is sufficient for shock initiation of the explosive.

J. S. Rinehart, *Compilation of Dynamic Equation of State Data For Solids and Liquids*, Report No. TP-3798, U. S. Naval Ordnance Test Station, China Lake, California, (May 1965).


## ABSTRACT

This compilation is a discussion of basic shock wave equations and theory of hydrodynamic impact. The impedence match method for determining Hugoniots is outlined. Empirical data from the Hugoniot can be used to calculate temperatures associated with the passage of shock waves. The bases for these calculations are described. A number of empirical equations, some of which are useful for computer calculations and others for graphical description are tabulated.

It has been found that in most instances, a linear relationship exists between shock and particle velocities. Constants appearing in this relationship are listed for a large number of materials. The bulk of the compilation consists of graphs and tables of shock velocity, particle velocity, pressure, relative volume and temperature associated with shocks.

For almost all materials, shock velocity is plotted against pressure and pressure against relative volume. In some instances where shock velocity is not linearly related to particle velocity, graphs relating the two have been drawn.

The final section is a reasonably complete bibliography listing the papers, reports, and books which contain dynamic equation of state data.

G. E. Seay, L. B. Seely, Jr., *Initiation of a Low-Density PETN Pressing By a Plane Shock Wave,*
J. Applied Phys. Vol. 32 pg 1092-7, (1961).


## ABSTRACT

Plane constant-pressure shock waves were used to initiate wedge-shaped pressings of PETN (pentaerythritol tenranite-rate). The shocks entered the PETN from brass or Lucite plates. Shock pressures in the plates and depths at which the PETN was initiated were measured with a streak camera. It was found that a 50-kbar shock in the brass was barely sufficient to initiate granular PETN pressed to a density of 1.0 g/cm$^3$. This corresponded to a derived pressure of about 2½ kbar in the PETN pressing. It was further shown that the intersitial gas had no effect on the depth of initiation.

D. C. Slade and J. Dewey, *High Order Initiation of Two Military Explosives by Projectile Impact*, Report No. 1021, Ballistic Research Laboratories (Jul 1957).


## ABSTRACT

Firings of right cylinders against bare Tetryl and Composition E show that the velocity for 50% initiation is a function of contact area but not of mass nor of the form of the projectile behind the contacting surface. The 50% velocity increases approximately linearly with the thickness of steel cover plates. Even with a one-fourth-inch steel cover plate no dependence on projectile mass was found with mild steel projectiles. A one-sixteenth-inch polystyrene plate increases the 50% velocity about as much as steel of the same thickness, while aluminum of greater thickness has little effect. At -58°C the 50% velocity for Tetryl is 15% higher than at 20 - 30°C while that for Composition E is not significantly different. Estimates of the time and position of the initiation show that it occurs within five microseconds of impact and in advance of the impacting surface. The theory that projectile impact initiates by transmitting a compression shock into the explosive predicts these results, but detailed interpretation requires further experimentation.

W. C. Sodoma, *Impact Sensitivity Test of MK-81 and MK-82 Bombs and Related Explosives, Fuzes, and Adapter Booster*, Air Proving Grounds Center Report No. APGC-TR-65-68, Eglin Air Force Base, Florida, (Sep 1965).


## ABSTRACT

APGC Project No. 2533W3 was conducted to evaluate the impact sensitivity of unfuzed MK-81 and MK-82, 250-lb, and 500 lb low-drag general-purpose bombs filled with H-6 or tritonal explosives. The impact sensitivity of the T-45E1 and T-46EA adapter boosters and unarmed M904E1 and M906 mechanical fuzes when installed in the MK-81 and MK-82 bombs and the FMU-54/B retarded bomb fuze installed in the MK-82 bomb were also tested. Unfuzed tritonal filled MK-81 and MK-82 bombs proved to be less sensitive to impact than unfuzed H-6 filled MK-81 and MK-82 bombs. When impacted against reinforced concrete targets, 3 ft. thick, the tritonal filled MK-81 and MK-82 bombs did not detonate prematurely at impact at velocities up to 723 fps and 903 fps, respectively, while the H-6 loaded MK-81 and MK-82 bombs detonated prematurely on impact at velocities of 429 fps and 507 fps, respectively.

When impacted against similar targets, to premature detonations of the unarmed tail fuzing components, (T-46EA adapter booster and M906 fuze), took place at impact velocities up to 851 fps. The unarmed nose fuzing components (T-45E1 adapter booster and M904 fuze detonated prematurely at impact and velocities as low as 571 fps. Data were obtained on only one test of an unarmed FMU-54/B fuze installed in the nose of the inert MK-82 bomb. At an impact velocity of 798 fps against a reinforced concrete target, 6 ft. thick, the fuze did not detonate prematurely. Based upon the results of this test, it is recommended that (1) retarded munitions be filled with tritonal rather than H-6 explosive and (2) using commands be made aware of the possibility of premature detonations due to high velocity hard target impacts when delivering retarded munitions using the M904 nose fuze/T-45E1 nose adapter booster combination and/or H-6 explosive filled bombs.

K. E. Spells and D. W. Woodhead, *Initiation of Detonation by Projectile Impact*, Nature, Vol. 179, pp. 251-253 (2 Feb 1957).


## ABSTRACT

This communication describes experiments in which the Buxton rotating-mirror camera (as adapted to schlieren photography) was used for photographing the impact of a mild steel fragment when projected with high velocity against the plane end of a cylindrical high-explosive pellet (the target charge) of diameter 1-25 in. and 3-8 in. long.

S. D. Stein, *Quantitative Study of Parameters Effecting Bullet Sensitivity of Explosives*, Technical Report No. 2636, Feltman Research and Engineering Laboratories, Picatinny Arsenal, Dover, New Jersey (Sep 1959).


## SUMMARY

Rifle-bullet sensitivity tests (Caliber .30) were conducted to determine the extent to which explosive-column length, thickness of confining wall, and kind of wall material affect the bullet sensitivity of commonly used explosives. Also studied was the feasibility of evaluating the test results quantitatively by measuring the magnitude of the shock wave generated when an explosive detonates.

The data obtained indicates that confinement has an important effect on the bullet sensitivity of explosives. As the thickness of the confining material is increased, the bullet sensitivity of the explosives tends to increase. For equivalent thicknesses, the explosives were more bullet sensitive in steel bombs than in aluminum bombs. The visual observations indicated that the bullet sensitivities of the explosives tend to decrease as the explosive column length is increased. The quantitative measurements indicated an opposite trend.

S. D. Stein and M. E. Pollack, *Development of an Improved Rifle-Bullet Impact Sensitivity Test*, Technical Report 2247, Samuel Feltman Ammunition Laboratories, Picatinny Arsenal, Dover, New Jersey (May 1956).

## SUMMARY

In the past the bullet sensitivity of explosives has been determined by using a rifle-bullet-impact bomb. The bomb consists of a black iron pipe nipple 2 inches in diameter and 3 inches long, and capped at both ends by standard 2-inch pipe caps. This test fixture was unsatisfactory because the bullet struck a curved surface, thereby introducing the undesirable variables which are inherent in firing at a curved surface. To eliminate this problem, a new bomb has been designed which presents a flat impact surface perpendicular to the line of fire. This new bomb retains a major deficiency of impact testing, however, in that the explosive reaction is only described qualitatively in terms of detonation, burning, smoke, or no reaction.

Ten explosives were tested in the new bomb. The reactions of 6 were similar to their reactions in the original bomb. The remaining 4 reacted differently, 50/50 pentolite was tested in the new bomb, which had been modified by varying the explosive column length and target plate thickness. The percentage of

detonations increased with each increase in target plate thickness and also increased as the length of the explosive column increased. There were no detonations in a total of 30 tests, 10 each with target plate thicknesses of 0.164, 0.250, and 0.375 inch, and an explosive column length of 1 inch. When the column length was increased to 2 inches, the percentages of complete detonations were 0%, 10%, and 40% for the same three plate thicknesses respectively. With a 3-inch explosive column, percentages of complete detonations were 0%, 40%, and 80%.

Increasing the target plate thickness of the new bomb from 0.250 inch to 0.375 inch increased the rate of detonation from 94% to 100% for 50/50 pentolite, from 31% to 50% for Composition B, and from 60% to 90% for 67/33 baratol. When 80/20 tritonal was used, however, the detonation rate decreased from 50% to 0%.

G. Svadeba, *Impact Sensitivity of Primary Explosives*, Report No. 2647, Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland (1 Nov 1952).


## ABSTRACT

The relative sensitivities of various primary explosives have been determined using 0.5, 1.0, and 2.5 kg weights. The sensitivities of several high explosives are included for comparison. The Bruceton Explosives Research Laboratory drop-weight impact machine was used with type 12 tools to determine the relative sensitivities. This relative order of sensitivities was the same within the realm of experimental error, regardless of the weight used. The use of the lighter weights for differentiating the sensitivities of primary explosives is indicated. Smaller differences in sensitivities are apparent and the method is more discriminating because the 50 percent heights are spread over a longer scale.

W. R. Tomlinson, Jr., *Compilation of Rifle Bullet Impact Data of Military Explosives*, Report From The Chemical Laboratory, Technical Group, Picatinny Arsenal, Dover, New Jersey, (1943).


## ABSTRACT

This report presents a compilation of data on the impact sensitivity of military explosives available in Technical Reports at the time the report was written. Also presented are --"Rifle Bullet Impact Tests on Explosive "D", Tetryl and Cyclonite Composition "C"--. The tests were performed on cast or pressed, confined explosive material.

W. R. Tomlinson, Jr., *Special Tests of Sensitivity of TNT*, Report No. 1217, Picatinny Arsenal, Dover, New Jersey (7 Dec 1942).

## SYNOPSIS

A study has been made to determine the effect of confinement on the difference in sensitivity of liquid and solid TNT. Sensitivities were compared on the basis of behavior in the Rifle Bullet Impact Test, the Drop Test, and the Explosion Temperature Test.

The data accumulated show that liquid TNT is considerably more sensitive than solid TNT under conditions affording good confinement. The sensitivity of liquid TNT increases with increasing degree of confinement and with increasing temperature.

M. L. Weiss, E. L. Litchfield, *Projectile Impact Initiation of Condensed Explosives*, Report of Investigations No. 6986, U. S. Department of the Interior Bureau of Mines. (July 1967).


## ABSTRACT

Studies were made on the projectile impact sensitivity of explosives by subjecting explosive samples to the impact of metal projectiles fired from a 0.50-caliber gun. The projectiles, in the form of right cylinders, made plane surface to plane surface contact with the explosives. Pressures in the explosive were investigated with an expendable pressure transducer in some instances.

The physical model of the projectile-explosive interaction describes, in principle, the duration of the peak shock pressure in terms of the projectile and explosive geometry and the steady-state penetration of the explosive. Of the explosives studied, liquid hydrogen-solid oxygen and liquid oxygen-solid or liquid hydrocarbon fuel were the most shock sensitive (requiring an initiating shock of about 1.0 kb Or 987 atmospheres pressure); cast TNT was the least sensitive (requiring an initiating shock of more than 110 kb pressure). Measurements of pressure in the explosive showed some moderate space resolution by the transducer and gave

Pressure distributions in agreement with expectations from the model of the shock processes. The appearance of the recovered projectiles and the calculated initiation shock pressures suggest that the solid explosives were initiated directly to high-order detonation, whereas the liquid explosives were probably initiated to low-order detonation--with a subsequent, later transition to high-order detonation.